Experimental management of a *Pinus pinaster* plantation for the conservation of *Diastella buekii*

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The largest population of *Diastella buekii*, previously considered extinct, occurs in a *Pinus pinaster* plantation in La Motte State Forest in the Berg River valley in the western Cape Province. Treatments were applied to 1-ha plots in a compartment of the plantation. Mortality in *Diastella* ranged from 87.5% to 100% between 1982 and 1987 with no treatment and with treatments of thinning the pines, burning under the pines, or both. Clear-felling the pines on 2 ha of the study site, and a burn three and a half years later, promoted regeneration, and resulted in a 29.4% increase in the population between 1982 and 1987. No Argentine ant invasion has been found on this site and seed dispersal by indigenous ants is not disrupted. A strong relationship between the distribution of *Diastella* and minor changes in relief suggests that depth to the water table plays a key rôle in the plants' distribution. The influences of adjacent plantations on the water table may adversely affect *Diastella* populations. It is concluded that *D. buekii* will become locally extinct unless the pine plantation is removed. No management problems are foreseen if these steps are taken.

Die grootste populasie van *Diastella buekii*, (Proteaceae: bedreigd), wat voorheen as uitgesterf beskou is, kom voor in 'n *Pinus pinaster*-plantasie in La Motte Staatsbos in die Bergriviervallei in die westlike Kaapprovinsie. Behandelings is toegepas op 1-ha persele in een van die vakke van die plantasie. Mortaliteit van *Diastella* het gewissel van 87.5% tot 100% tussen 1982 en 1987 waar daar geen behandeling toegepas is nie en waar dunning van die denne, brand onder die denne, of albei toegepas is. Kaalkap van denne op 2 ha van die studieperseel, met 'n brand drie en 'n half jaar later, het verjonging bevorder en tot gevolg gehad dat daar 'n toename van 29.4% was in die populasie tussen 1982 en 1987. Geen Argentynse miere is op die studieperseel gevind nie en saadverspreiding deur inheemse miere is nie ontwrig nie. 'n Sterk verwantskap is waargeneem tussen die verspreiding van *Diastella* en geringe veranderings in die relief, wat daarop dui dat die diepte tot by die watertafel 'n sleutelrol speel in die plant se verspreiding. Die invloed van aangrensende plantasies op die watertafel mag *Diastella*-populasies nadelig beïnvloed. Daar word dus tot die gevolgtrekking gekom dat *D. buekii* plaaslik mag uitsterf tensy die denne-plantasie verwyder word. Geen bestuursprobleme word verwag indien hierdie stappe gedoen word nie.

Keywords: Conservation, *Diastella buekii*, disturbance, endangered species, population dynamics

Introduction

The habitat of *Diastella buekii* (Gandoger) Rourke has been extensively altered by man, and remaining populations occur mainly within pine plantations. Rehabilitation of the habitat is impractical, and the concept of conserving the species within the context of plantation management presents a pragmatic solution. *D. buekii* is a low prostrate member of the Proteaceae, forming dense patches up to 10 m in diameter. The species was assumed to be extinct when the genus was revised in 1976, having been last collected in 1934 (Rourke 1976), but was rediscovered in the La Motte State Forest by Mr A.V. Milewski of the Bolus Herbarium in September 1976. Hall & Veldhuis (1985) placed the species in the conservation category defined as 'endangered', in immediate danger of extinction if the factors causing decline continue operating. Included are taxa whose numbers of individuals have been reduced to a critical level or whose habitats have been so drastically reduced that they are deemed to be in immediate danger of extinction.

Herbarium records show that the species had a historical distribution between Franschhoek and Paarl, on the sand flats of the upper Berg River valley, at 200 to 300 m above sea level, in the western Cape Province (Rourke 1976). These sand flats are farmed now, principally as vineyards, and *D. buekii* has been eliminated in most places. Most unploughed land in this area supports pine plantations or dense stands of woody alien weeds.

Three major populations of *D. buekii* are known. In accordance with the policy of Hall & Veldhuis (1985), exact localities will not be disclosed. The most substantial population occurs in La Motte State Forest (19° 05′ E, 33° 54′ S). In 1979 this population comprised some 2 000 individuals under a 78-ha plantation of *Pinus pinaster* Aiton (van Wilgen & Forsyth 1980). Another, smaller, population also occurs on La Motte State Forest in a *Pinus radiata* D. Don plantation and an area severely infested with *Acacia longifolia* (Andrews) Willd. The portion of the population outside the plantation was burnt in 1982. Adult plants were killed by the fire but good seedling regeneration occurred (C.J. Burgers, pers. comm.). The third population is on a nearby private farm. It comprises an unknown number of individuals growing on unused land infested with *Pinus* species, *Hakea sericea* Schrad. and *Acacia longifolia*.

This paper reports on the results of experimental plantation management on *Diastella* populations on 5 ha of

the plantation with the larger *D. buekii* population. The study includes aspects of the biology of the species related to regeneration and mortality, and a preliminary account of the possible rôles of ants and rodents. The distribution of individuals in relation to local relief is determined and discussed in relation to conservation measures.

The study area

All the known sites occur on deep, coarse quartzitic sands. These sands are locally derived alluvial and fluvial deposits (Schloms *et al.* 1983). In all the sites the water table is high and seasonal waterlogging is evident. *Diastella buekii* does not appear to tolerate waterlogging and is found on relatively higher ground. *Passerina vulgaris* Thoday, *Leucadendron salignum* Bergius and *Leucospermum hypophyllocarpodendron* (L.) Druce are typical elements of the indigenous vegetation which persists in places.

The site of the larger La Motte State Forest population was planted with *Pinus pinaster* in 1971 and 1972. The principal motivation behind the planting was to bring this outlying portion of State forest, which served no apparent alternative purpose then, into economical use. The initial planting density was 1 330 stems per hectare. In 1979 the first thinning was carried out (to 750 stems per ha), and the remaining trees were pruned. Felled trees and branches (slash) were left on the ground, and many *Diastella* plants were covered. The size of this population was estimated as 2 035 individuals in 1979, before the thinnings and prunings. Approximately 79% of the plants surveyed had a diameter greater than 1 m, and 78% of the plants were classified as having more than 75% of the crown alive (van Wilgen & Forsyth 1980). In 1981, 5 ha of this plantation were made available for experimentation.

Methods

Population studies

A compartment in the plantation was selected for even distribution of *Diastella* plants, where it was possible to subdivide the area equally with some individuals in each treatment, although it did not contain the highest density of *Diastella*. Seven adjacent 1-ha strips were demarcated across the compartment. Each strip was 34.3 m wide, forming a parallelogram with sides of 291.6 and 38.5 m.

All *Diastella* individuals on these strips were enumerated in October 1982. The diameter of the area covered by each individual was measured on a line parallel to the long side of the strip, and on a line perpendicular to the first. The proportion of living crown was estimated and an index of plant size was calculated as the product of the two diameters and the proportion of the crown alive. The number of flowers on the plant was recorded in the categories of 0 (no flowers), 1 (1 to 10 flowers), 2 (10 to 20 flowers), 3 (20 to 40 flowers), 4 (40 to 60 flowers) and 5 (more than 60 flowers). The amount of pine litter on the plant was estimated as 0 (no litter), 1 (scattered needles on the plant), 2 (up to 25% of the plant covered), 3 (25 to 50% of the plant covered), 4 (50 to 75% of the plant covered) or 5 (more than 75% of the plant covered). Each plant was tagged and its position mapped. In later surveys new individuals were tagged and mapped. The positions of new seedlings in the later surveys relative to the adult plants were used to derive estimates of seed dispersal distances.

Table 1 Treatments applied to plots in a *Pinus pinaster* plantation in La Motte State Forest containing *Diastella buekii* individuals. All plots were planted with 1 330 *P. pinaster* stems per ha in 1971/1972 and thinned to 750 stems per ha in 1979

Plot	Area (ha)	Treatment
1	2	Clearfelled (1983) and burnt (1987).
2	1	Burnt (1987) under pines (750 stems per ha).
3	1	Pines thinned to final density of 375 stems per ha and slash removed (1984), and burnt under pines (1987).
4	1	Pines thinned to final density of 375 stems per ha and slash removed (1984); no burning.
5	2	Control; standard management procedure (thinned to 375 stems per ha in 1986, slash not removed); no burning.

Treatments were applied to four plots in the allocated 5 ha (plots 1 to 4 in Table 1), with a fifth plot of two untreated hectares to serve as a control. All slash from fellings and prunings was carried out of treated plots to minimize damage to the *Diastella*. Enumerations were repeated, after the clearing and thinning operations, in October 1984, October 1985 and November 1986. Plot 5 was thinned as a standard management procedure with the rest of the plantation in 1986. Plots 1 to 3 were due to be burnt in the summer of 1985/1986 but vegetation regrowth on the clearfelled area (plot 1) was insufficient to carry a fire. Therefore burning was postponed until 13 April 1987. Pine regrowth on the clearfelled area was cut down and allowed to dry *in situ* before the burn, to achieve a reasonable fire intensity. In plots 2 and 3 the pine needle litter was cleared up to 500 mm away from each pine tree trunk before the fire to minimize damage to the plantation. A further enumeration was undertaken in October 1987.

Ant and rodent communities

A trapping grid was set out in November 1984 to determine the species of ants present. Four parallel lines of 11 trap stations at 10-m intervals were set out, one along the base line of plot 1, one in the middle of plot 1, and between plots 1 and 2, and 2 and 3. A small piece of meat on a tooth pick was set out at each trap station in the morning. In the mid afternoon the ants on the meat at each station were rinsed off in a phial of alcohol for identification. Snap traps with wholewheat bread as bait were then set out at the trap stations to determine the small mammal species present. The traps were left out for two nights and checked each morning, giving a total of 88 trap nights.

Effects of relief on distribution

Local relief in the clearfelled area (plot 1) was surveyed on 8 October 1987. A point in the centre of the outer edge of the plot was used as a reference point. The elevations, relative to this datum, of points at 10-m intervals along the edge were measured using a dumpy level and a height rod graduated in cm. A further seven lines, 10 m apart, were set out parallel to the first, and the elevations of points at 10-m intervals along each line were measured in relation to the reference point.

The survey points were grouped into elevation classes of 0.5-m intervals and plotted. Zones of different elevations were delineated by connecting the midpoints of the distances between points where elevation classes differed. The distribution of *Diastella buekii* plants in 1987 was superimposed on the plot. The frequencies of occurrence of *Diastella* individuals in each elevation class was compared with a theoretical distribution. This distribution was based on the area covered by each interval, as a fraction of the total area, and assuming a uniform distribution of plants.

Results

Population studies

The effects of the treatments on the numbers of *Diastella* in the strips are shown in Figure 1. Mortality of *Diastella* in the area clearfelled in 1984 (plot 1) was 58.8% between 1982 and 1984. Some regeneration took place after the clearfelling, and again after the burn, giving a 29.4% increase in the population over the entire study period. The edges of the canopy mats of most of the adult plants were scorched back in the fire, but major portions of the mats appeared unaffected. Only one of the 23 adults in plot 1 at the time of the burn was killed by the fire. Dense regrowth of *Pinus pinaster* occurred in plot 1 after clearfelling.

Populations in the other treatments also declined markedly between 1982 and 1984. Mortality was 60% in the unthinned plot 2, 51.1% in plots 3 and 4 which were thinned and 47.6% in the standard management plot. Mortality between 1982 and 1987 varied between 87.5 and 100% and mortality in the fire was high. There was no recruitment in any of the treatments under the pines apart from one seedling found after the fire in plot 3.

The sizes of the original plants in the clearfelled area (plot 1) increased in the study period, but patterns of growth are obscure for the other treatments (Figure 2). No clear pattern emerged with the flowering index (Figure 2). Apart from the clearfelled area, the amount of pine litter on the *Diastella* plants tended to increase with time (Figure 2). Plants under a lot of pine litter usually died. Table 2 shows the relation between the amount of pine litter on *Diastella* plants recorded in the 1982 survey and their survival in the period 1982 to 1984 (chi-square = 64.2, significant at $P < 0.001$).

The mean distance between seedlings present in 1986 and 1987 and the nearest extant adult plant positions is 10.2 m (variance = 103.6 m, minimum = 1 m and maximum = 40.2 m). If the positions of the adults which died earlier are included then the mean distance between seedlings and the nearest adult position is 6.4 m (variance = 20.1 m, minimum = 1 m and maximum = 21.1 m).

Ant and rodent communities

No Argentine ants were caught on the ant trapping lines. The following indigenous ant species were trapped: *Ano-*

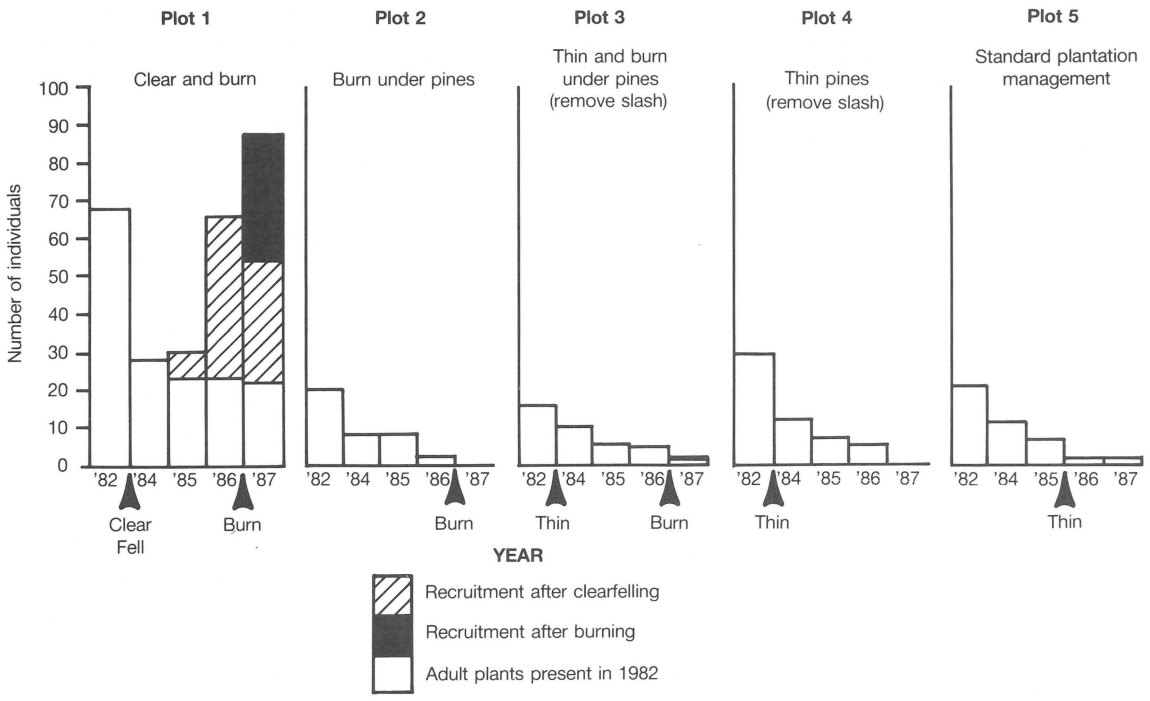

Figure 1 Changes in numbers of *Diastella buekii* individuals over time on treated plots in a *Pinus pinaster* plantation in La Motte State Forest. See Table 1 for description of treatments.

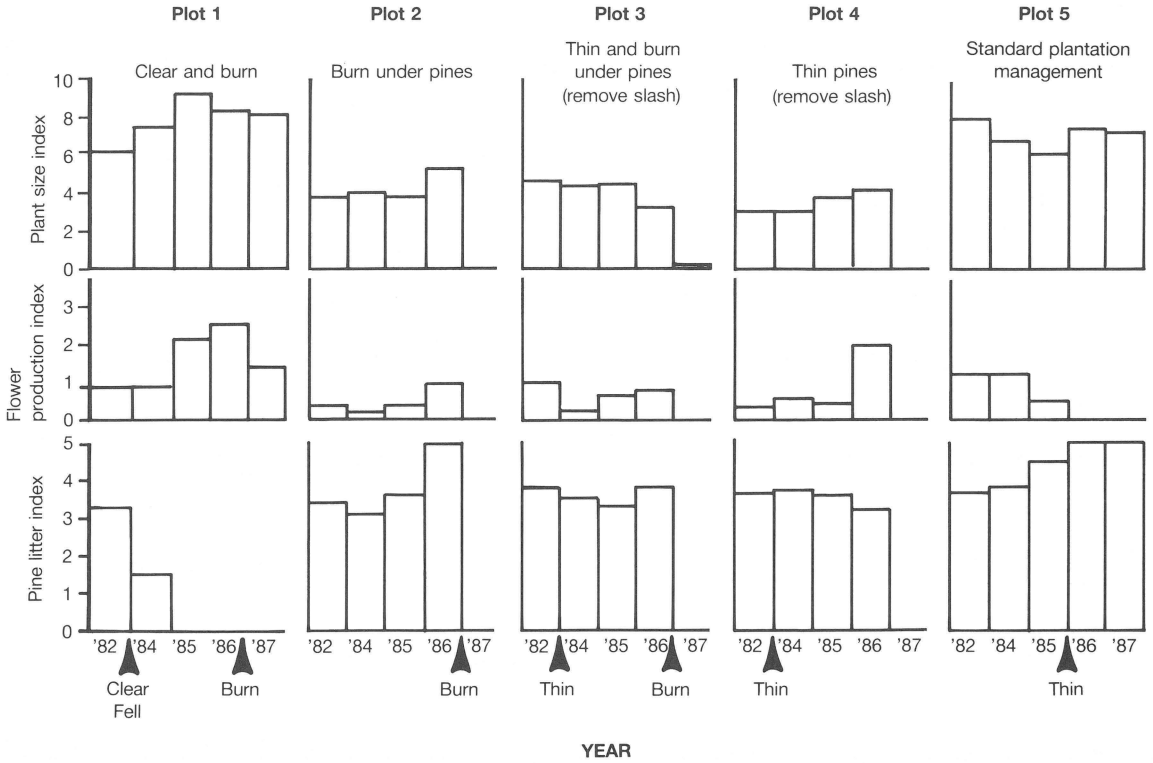

Figure 2 Changes in the size of *Diastella buekii* plants, flowering index and pine litter index on the plants on treated plots in a *Pinus pinaster* plantation in La Motte State Forest. See text for description of indices and Table 1 for description of treatments.

plolepis custodiens (Smith) (six trap stations), *Acantholepis capensis* Mayr (two trap stations), *Crematogaster peringueyi* Emery (six trap stations) and *Tetramorium quadrispinosum* Emery (six trap stations). No Argentine ants were observed in the area for the duration of the study, and the indigenous ant community appeared to be maintained. No rodents were caught on either night.

Effects of relief on distribution

Diastella buekii is not distributed proportionally in areas of different elevation classes (Table 3). Higher densities occurred on the higher elevations (chi-square = 92.55, $P < 0.001$).

Table 2 Contingency table showing the relation between the amount of pine litter on *Diastella buekii* plants in 1982 and their death or survival 2 years later (1984). No plants were completely free of pine litter in 1982. Chi-square = 64.2, significant at $P < 0.001$

	Outcome (1984)	
Amount of pine litter (1982)	Survive	Die
More than 75% of the plant covered	7	48
50 to 75% of the plant covered	5	18
25 to 50% of the plant covered	17	10
Less than 25% of the plant covered	28	5
Scattered needles	14	2

Discussion

Population studies

Diastella buekii tolerates physical disturbance and fire. Despite considerable trampling and the felling of pine trees in the clearfelling and thinning operations, mortality was not greater than in the untreated areas. Clearfelling promoted regeneration, the seeds probably being stimulated to germinate by temperature fluctuations caused by the exposure of the soil to full radiation after removal of the canopy, as proposed by Brits (1986). Three of these seedlings were producing up to 10 flowers

Table 3 The effects of relief on the distribution of *Diastella buekii* plants on plot 1 in La Motte State Forest in 1987. The expected frequency was derived by assuming a uniform distribution of plants and dividing the total present amongst the elevation classes according to the proportion of the area covered by that class. Elevation classes indicate the height above the lowest point on the site. (Chi-square = 92.55, significant at $P < 0.001$)

Elevation class	Expected frequency	Actual frequency	Class contribution to chi-square
0.0 to 1.0 m	21.5	8	8.5
1.0 to 1.5 m	30.1	11	12.1
1.5 to 2.0 m	19.8	20	0.02
2.0 to 2.5 m	12.0	39	60.7
Over 2.5 m	2.6	8	11.2

per plant by 1986.

Diastella plants in the clearfelled area (plot 1) were not adversely affected by fire. Despite the felling and drying of the pine regrowth in the clearfelled area, there was seldom evidence of the fire penetrating the canopy mat of the *Diastella*. The mortality in fire of *D. buekii* under the pines is comparatively higher than in plot 1. This is attributed to the needle layer on the *D. buekii* carrying the fire over the mat of the plant and killing it. The contradictory observations of destroyed adult plants in the smaller La Motte State Forest population (see Introduction) in 1982 are possibly attributable to the dense tall stand of *Acacia longifolia* in the area which burnt and may have raised the intensity of the fire. No overtopping of adult *Diastella* by other indigenous species was observed in the study area. There was evidence on most plants in the clearfelled area of vigorous post-fire growth, and most plants had grown larger than their pre-fire size in the 7 months before the post-fire survey. Seedling recruitment after the fire again probably resulted from exposure of the soil surface. The minimal mortality which did occur in the clearfelled area between 1986 and 1987 was not necessarily the result of the fire. The same applies where the burn was carried out under the pines, but in this instance the increased pine litter on top of the plants probably caused increased mortality in fire.

Despite clearing the litter away from each pine tree trunk, all trees in the burnt area appear to be dying. Heavy needle fall followed soon after the fire, rapidly returning the litter mat to its pre-fire state and negating the removal of the litter by the fire. This needle fall is possibly the factor which prevented successful regeneration of *Diastella* after the fire. The only seedling which was present in the area which had been thinned and burnt was on a patch of bare ground under an opening in the forest canopy.

Diastella is capable of growing up through slowly accumulating pine litter, maintaining its size and vigour. This explains the lack of clear trends in size and flowering under the pines. Most surviving *Diastella* plants in the plantation were on the edge of the plantation and were not subjected to the same litter fall as other plants. Once the rate of pine litter accumulation exceeds the ability of the *D. buekii* shoots to grow through the litter, the plant dies. Most of the mortality occurred between 1982 and 1984. This appears to result from the material from earlier thinnings and prunings covering many plants. The mortality of plants covered with pine litter supports the concern expressed by van Wilgen & Forsyth (1980) about the effects of the plantation on the *Diastella* population. In the present study the mortality under pines between 1982 and 1987 was at least 87.5%. Similar *Diastella* mortality in the rest of the plantation between 1979 and 1987 means that less than 300 plants survive from the 2 035 estimated to be present in 1979 by van Wilgen & Forsyth (1980).

The distances between seedlings and the nearest adult plant give some idea of effective dispersal distances. The distances reported here are not great and conform with those reported by Slingsby & Bond (1982), Bond & Slingsby (1984) and Brits (1987). The reduction of the mean seedling-to-adult distance and the variance of the mean through the inclusion of the positions of dead plants suggests that many seedlings came from the seeds of these dead adults. Since most mortality occurred in the period 1982 to 1984, and the seedlings germinated in the winter of 1985 and 1986, this in turn suggests that seed longevity in the soil exceeds one year, as is often assumed for myrmecochorous seeds (Slingsby & Bond 1982; Bond & Slingsby 1984; Brits 1986, 1987).

Diastella buekii exhibits a life history typical of the GI pattern described by Noble & Slatyer (1980). Species following this pattern are killed in a disturbance and regenerate from stored seed in the period immediately after disturbance and not in established communities. Soil-stored seed pools may outlive the adult plants, but the pool may be exhausted after the next disturbance. Seedlings must mature and replenish the seed pools before another disturbance, or the species will become locally extinct. When adult *Diastella* plants die under pines, the death is not related to a germination-inducing disturbance (such as fire or clearfelling) and the seeds remain dormant. Should the period between the death of the adults and a disturbance exceed the longevity of the seeds, then the species will become locally extinct. Richardson & van Wilgen (1986) found that myrmecochorous species were almost entirely eliminated from a mesic mountain fynbos community after 35 years of afforestation with *Pinus radiata*. These authors suggested that such species may re-appear after a disturbance, depending on the longevity of the soil-stored seed pool. The longevity of *Diastella* seed in soil is not known, but allowing the pines to mature before clearfelling will reduce the success of subsequent regeneration.

The *Pinus pinaster* killed in the burning treatments will have to be removed as they will present a source of pathogenic infections for the rest of the plantation. This will terminate the experiment but will provide further observations on regeneration after clearfelling.

Ant and rodent communities

The seeds of all *Diastella* species are considered to be myrmecochorous (ant dispersed) (Slingsby & Bond 1982). This appears to hold true for *D. buekii*. The seeds are enclosed within a thin papery elaiosome and ripe seeds disappear quickly from flower heads. Myrmecochory is common in south-western Cape shrublands and is an important factor in seedling recruitment (Bond & Slingsby 1984). In the dispersal process seeds may be placed in ant nests, beyond the reach of rodent granivores.

The Argentine ant (*Iridomyrmex humilis* Mayr) has invaded some shrublands in the south-western Cape, displacing native ant communities and disrupting the regeneration of myrmecochorous species (Bond & Slingsby 1984). Argentine ants are usually introduced to an area in material such as soil and refuse (Smith 1936), and the proximity of the *Diastella* site to a major road and plantations increases the risk of introduction of

these ants.

Ant communities in mature pine plantations may be expected to be depauperate owing to the low diversity of vegetation (Donnelly & Giliomee 1985). The study site was checked for the presence of Argentine ants to see if there was any point in arguing for the removal of the plantation (if the *D. buekii* regeneration process is disrupted by Argentine ants, then local extinction is likely even without the plantation). The observation on the lack of a rodent population is consistent with observations in 15-year-old *Pinus patula* plantations in Malawi (Happold & Happold 1987), and the situation at the other *D. buekii* sites is probably similar. Although rodent populations will increase after clearfelling (Happold & Happold 1987), the absence of Argentine ants means that indigenous ant species will be present and will bury the seeds, thereby reducing seed predation by rodents.

Effects of relief on distribution

Visible differences in the indigenous shrubland community occur with small changes in elevation, and appear related to the water table. Species tolerant of seasonal waterlogging such as *Drosera* spp. occur on the lower ground, while the shrubs such as *Leucadendron salignum* and *Passerina vulgaris* occur on the higher ground. *Diastella buekii* also appears sensitive to water table levels and is found on the higher ground. Pine plantations are known to use more water than indigenous shrublands (Bosch & Hewlett 1982, van Wyk 1987) and the presence of a plantation may lower the water table. Although there is no evidence in this study that lower water tables will adversely affect existing individuals, the possibility exists as observations indicate that *Diastella* does not occur on elevated deep sands. Fluctuations in the water table after clearfelling may impair regeneration.

Conclusions

The clearfelling operation in the study was the first disturbance after approximately 12 years under a pine plantation. Regeneration after this disturbance, and after the fire some three and a half years later, was satisfactory. These observations, the limited mortality of adults under reasonable fuel loads, the short juvenile period, and the intact myrmecochorous process suggest that *Diastella* could be successfully managed by a relatively short interval between fires (8 to 12 years) after removal of pines.

There seems to be no feasible way of conserving *Diastella buekii* within a plantation habitat. Of the methods studied, complete removal of the pines is the only effective means of ensuring the species' survival. Furthermore, a *Diastella* preserve surrounded by a plantation would be subject to changes in the water table and copious pine regrowth such as that which occurred on the clearfelled area. It would seem appropriate that the entire 78-ha plantation at the site of the larger La Motte State Forest population should be removed, preferably before the levels of viable soil-stored seeds decline. It would also seem appropriate for the State to manage this area as a preserve for *Diastella buekii* and other indigenous species of the Berg River valley.

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